**Ground Improvement**
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**Lecture – 15**
**Deep Dynamic Compaction (contd.)**

Once again, let me invite you to this lecture. In the previous lecture I have mentioned that, deep dynamic compaction on different aspects. I have mentioned that, I will try to show the application through a problem, whatever we have discussed, I will try to show how you have to apply those equation or we have to refer those tables, all those things I will try to show with an example problem in this. So, let me go to the slide in the problem.

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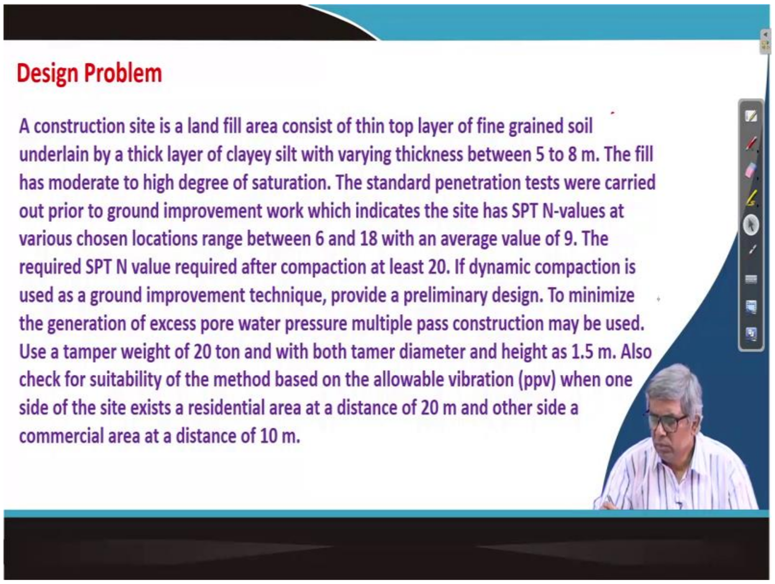


And the problem is here little lengthy looks. You can see here a construction site is a land fill area consist of thin top layer of fine-grained soil underlain by a thick layer of clayey silt with varying thickness between five to eight meters. The fill has moderate to high degree of saturation. The standard penetration tests were carried out, prior to ground improvement work which indicates the site has a SPT N values at various chosen location ranges between six and eighteen with an average value of nine.

The required a SPT N value after compaction at least twenty. The required SPT N value after compaction at least is twenty. If dynamic compaction is used as a ground improvement technique, provide a preliminary design, provide a preliminary design, and means what actually? First of all, whatever soil is explained here or described here, based on these you have to first of all decide, what is the depth of improvement required?

That is one, then you have to based on given description of the soil you have to classify the soil. We have classified the soil in three different categories. And that will help you to select $n_c$ value. So, where this, based on this description of the soil, you have to categorize the soil type and based on that you can select them value of $n_c$. And again, based on the description of the profile and soil type, you have to decide, what is the depth of improvement required?

Two things actually from the given, given information you can find out. Then another thing is that, that SPT N value at the site after compaction required is twenty. But at the site SPT test already conducted and different location SPT value observed, which varied between six and eighteen, somewhere six and somewhere eighteen. Still, all are below twenty, but since it is varying between six and eighteen, so average value is around taken as depending upon how many numbers of six, how many numbers of 18.

So, average value came actually nine. That means we have to improve the soil in such a way, SPT value should improve from nine to twenty. That is the requirement, the target value is SPT twenty. And so, this is the two things that means, one is actually depth of improvement. The classic categorizes the soil, that two things. And based on these now, you have to design that will, what to be designed?

That deep dynamic compaction is mentioned. In that design, what is that, you have to decide a tamper weight. And here actually porosity is mentioned tamper weight already, 20 ton. Then you have to decide the height. And height of top, that is one thing. Then you have to decide how many passes is required. And each pass how many drops required.

These are the actual design, whether the type of soil described here, whether you should go for a single pass or two pass or three pass actually that to be decided, that I will explain how, how we are going to, how we are deciding that. Those are the things that means, you have to take decision that depth of improvement based on the given information. Then categorize the soil based on given information.

Then based on the soil type you have to decide, whether you will be doing by a single pass or double or triple pass. Then, if the tamper weight is not given, you have to decide a tamper weight and dimension. If it is given, then you have to, based on that you have to decide what is the height required. Once, you know the weight and height, any total energy requirement is required is known.

And if you decide one or two passes that means, one person how many, how much quantity of energy is required that is also known, then what you have to find out? If single drop how much energy and to achieve this much energy how many drops. This is the preliminary design. This we have to do one by one, and then to minimize the generation of excess pore water pressure, multiple pass construction maybe used.

This is the, already is mentioned here. And, and we will see that and use a tamper weight of 20 ton. And with both temper diameter height is 1.5 meter, that is also given. Also, check for suitability of the method based on the allowable, allowable vibration PPV, peak particle velocity when one side of the site exists a residential area at a distance of 20 meter. And other side, a commercial area at a distance of 10 meter. One side is residential area, distance is 20meter.

Other side is commercial area, with a 10meter distance. And peak particle velocity calculation there is a method we know. And based on the distance, we can find out the velocity. And again, that peak particle velocity acceptance for different types of buildings or different types of location is different. We have to refer the table and then you have to say that this project is acceptable. These are the things we have to do.

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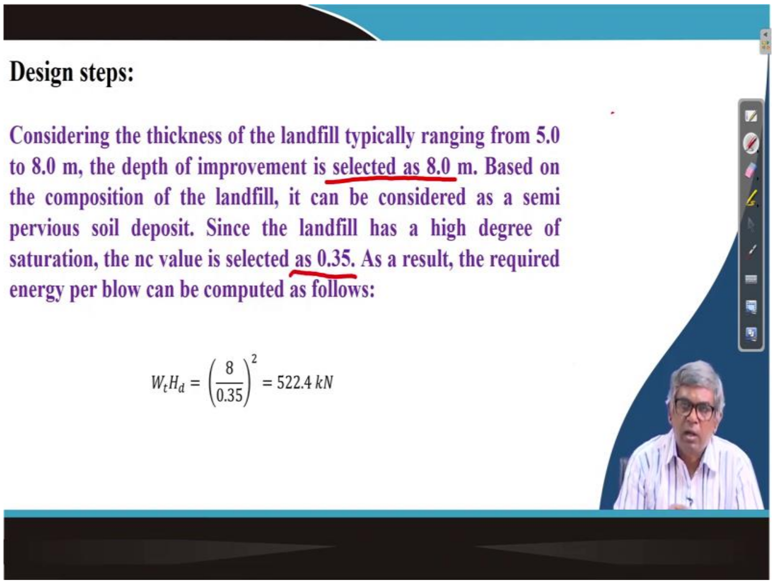


So, let me come to this. How we are going you can see that, considering the thickness of the landfill typically ranging from 5 to 8 meter. So, landfill is, landfill material is 5 to 8meter. When it is a landfill, that material has to be densified. Because of that, that means depth of improvement to be selected as eight. So, that is what? First decision is, depth of improvement is 8meter.

Next is, based on the composition of the landfill, the material is given silty and the top fine soil, it can be considered as a semi pervious file deposit, semi pervious not, it is not sand. And since the landfill has a high degree of saturation, then nc value can be selected as 0.35 I have shown here. How you are getting that one? Let me show you in the next one, next slide.

$$W_c H_d = \left(\frac{8}{0.35}\right)^2 = 522.4kN$$

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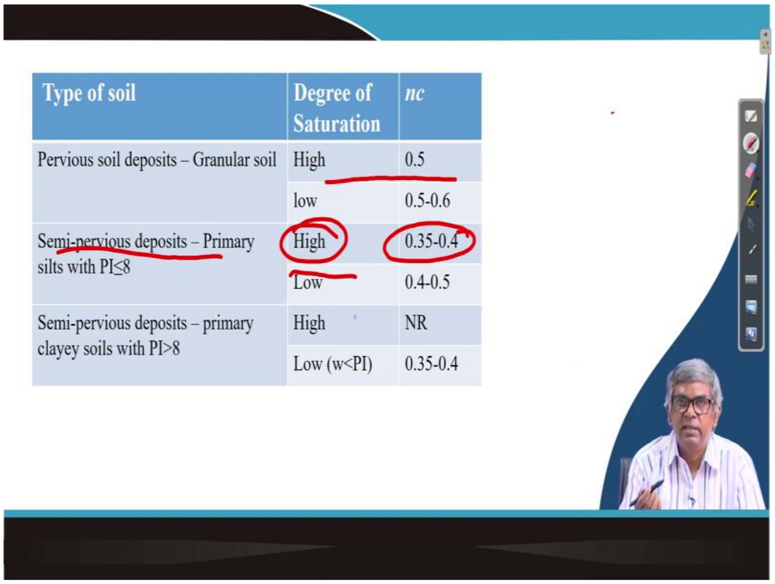


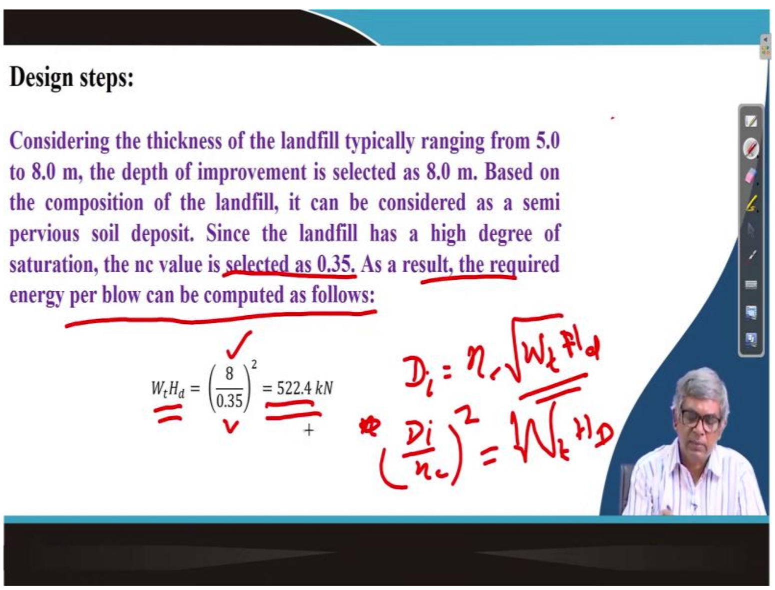


I can show you here, you can see here that we have decided that soil is a semi pervious, and high degree of saturation. Then the value is typically 0.35 to 0.4. So, that means, I can select value in between. So, 0.35 to 0.4 is a very small range. So, better we take as 0.35, that is what it is shown here. So, once again that equation to be required. So, that is what I was showing, I will show here, you can see here, 0.35 is selected.

As a result, the required energy per blow can be computed; you can see that your equation was depth of improvement equal to nc under root Wt Hd. So, Wt and Hd is an energy, is it not. So, the weight falling this much height, this product is energy. So, this one you can see. We can see that, Di by $n_c$ whole square, nothing but Wt Hd.

$$D_i = n_c \sqrt{W_t f^{'} d}$$
$$\left(\frac{D_i}{n_c}\right)^2 = W_t H_d$$

That is what is done here, Wt $H_d$ equal to depth of improvement, improvement is 8 $n_c$ value is 0.35 and from that energy in a drop, how much energy is already required or that ways already decided 522.4. And how it is 0.35 etc already I have shown you, while again moving I will show you again, once again.

let me show if it is, some other material, pervious material, high degree of saturation, low degree of saturation, this table from the table $n_c$ value can be taken. And this thing already I have told you in the lecture twelve, thirteen and that area. Similarly, if it is in our case this is the soil. So, the $n_c$ value can be taken this one. That is the way we have selected.

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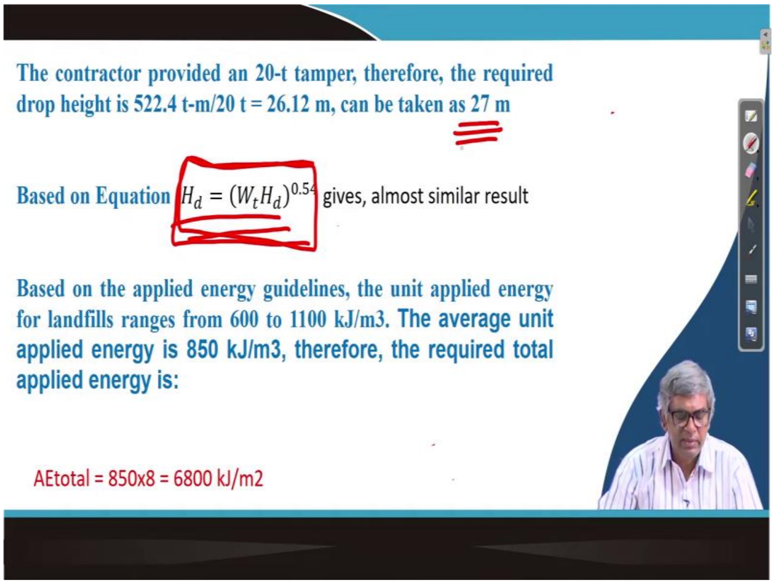
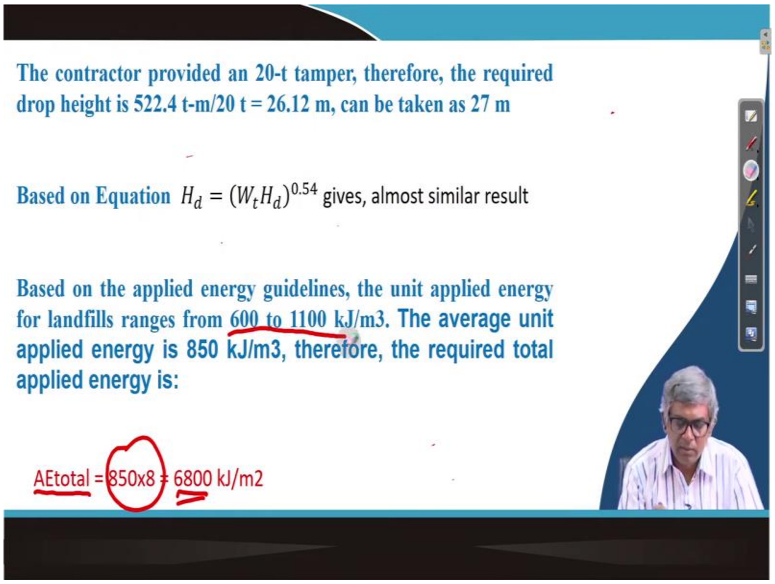



$$H_d = (W_t H_d)^{0.5}$$

$$AEtotal = 850 \times 8 = 6800 kJ / m^2$$




Next part is the contractor provided actually 20ton tampers, suppose already mentioned. Therefore, the required drop height is, will be required 522.4 is the energy required and the drop height is, tamper weight is 20 then it is 26.12. So, we can take suppose 2meter drop height. And there is an equation also I have discussed before, that $H_d$ and drop height and weight of tamper, there is a relationship and there is an empirical equation is given.

And this empirical equation also you can try, it comes come close to that, very difficult to solve because both side $H_d$ is there and very difficult to solve. But if you can try assuming some $H_d$ value, the depth site you calculate this one then $H_d$ should come same. Accordingly, if you do that, it comes around 29 meter or but they are quite close. But this is done based on energy calculation, let us do with this 27meter.

Now, based on the applied energy guidelines, the unit applied energy for landfill ranges from 600 to 1100 that is again I have shown here, during lecture, in the table form different soil, what is the unit energy is there? And I will show you once again in the next slide is there. That particular landfill soil, the energy required energy, our energy is 600 to 1100 kilojoules per meter cubed.

And you can take any value in between. If you know the oil is lot towards the lower side, then you can take 600, you can decide the soil is higher side you can take higher value 1100. But we do not have much clear idea. So, based on that, because of that we can take the average value and the 600 and 1100, this average value comes around 850 kilojoules per meter cube. This is the value I can take, the required, energy requirement, applied energy requirement.

And then if I know that, and 850 a depth of improvement is 8, then a total can be calculated 850 multiplied by 8 is 6000, 6800 kilojoules per meter square area. This is the one done. Now how it is selected 600 to, 600 to 1100 that I will show you in the next slide, the table is there, which already I have discussed in the previously, previously in the lecture.

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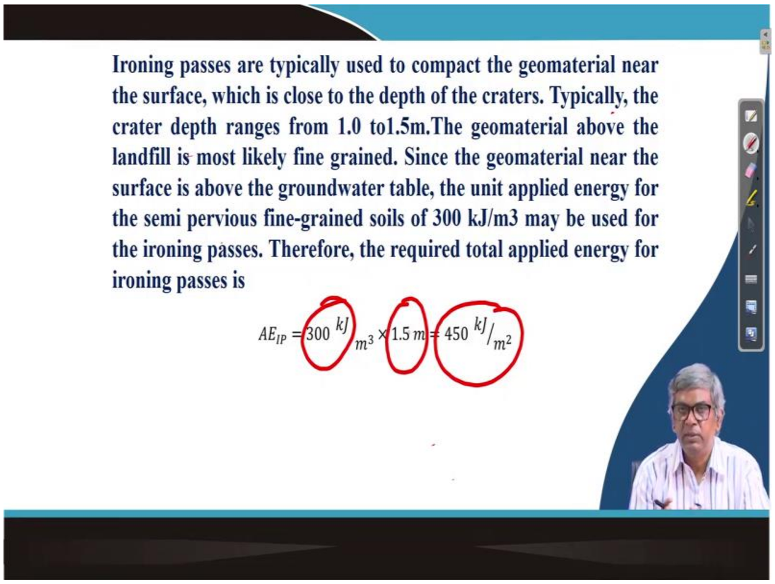


And now, to decide that energy requirement, you know total energy is 6800. And energy requirement by the heavy method, heavy impact method, so how to find out that, you know that deep dynamic compaction there will be the ironing pass. And then ironing pass, how much energy if you can find out, that can be subtracted from there.

$$AE_{Jp} = 300kJ/m^3 \times 1.5m = 450kJ/m^3$$

And then we will get the energy required by the tamping, so that, that to be determined. So, that how we are doing that, you can see here. Ironing pass are typically used to compact the geo-material near the surface, which is close to the depth of craters. And typically, the crater depth ranges from 1 meter to 1.5 meter. The geo-material above the land is most likely fine grained, it is also mentioned.

Since the geo-material near the surface is above groundwater table, the unit applied energy for this semi pervious fine-grained soils of 300 kilojoules that is also from the table I will show you that, taken maybe used. Therefore, you can see here. This is the energy calculation shown for energy, ironing pass, ironing pass that, that type of soil, surface soil, fine grained soil, that energy is 300 kilojoules per meter cube.

And depth actually ironing pass general you do equal to the crater depth; the crater depth comes around 1.5 meter or so. So, we are taking that. So, if I do that, it is coming 450 kilojoules per meter square. It was 6800 total, 450 only for energy sorry, ironing pass. So, remaining has to be by heavy method by tamping. So, that one now, I will show you those table actually, which I was missing in the, in between.

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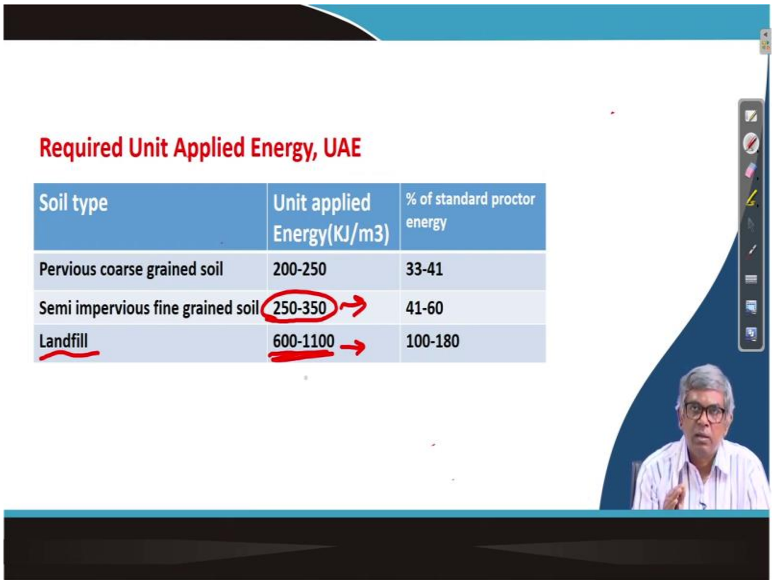


The table is here, you can see that what we have taken for landfill, the value is, it is 600 to 1100 kilojoules per meter cube and whereas, this one semi-impervious fine-grained soil 250 to 350. We have taken 300. This one is used for calculation of iron pass, the energy requirement by the iron pass. And these values, taken average value of this is taken to calculate the energy for, average energy for the total requirement.

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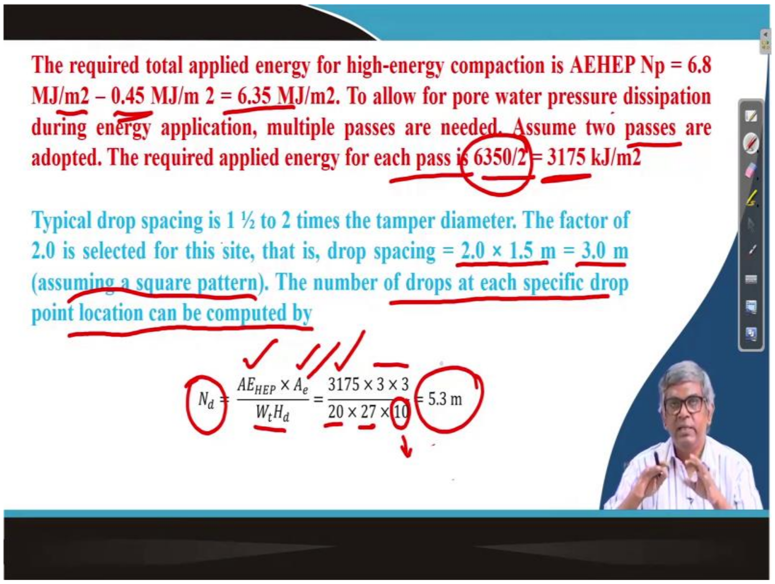


Now, we can see that required total applied energy for high energy compaction is 6.8, 6800 means, 6, 6.8 mega joules you can write, 6.8 mega joule minus 0.45 mega joule, 450 means, 0.5 that means 6.35 mega joule per meter square. And since it is recommended multiple passes, so here pore water pressure distribution etc. We can assume the two phase, two passes. And if you decide for two passes and this is the total.

So, each pass actually energy requirement is 6350 divided by 2 that means, 3175 kilojoules per meter square. So, each pass this much energy required. Now, typical drop spacing is, that to be recommend how much, what is the spacing of the drop. So, one, one and a half to two times the damper diameter. The factor of safety 2 is selected here. Then, we are taking here the 2 multiplied by 1.53 meter.

And assuming a square pattern, the number of drops at each specific location point location can be now calculated by this, you can see this number of drops equal to AE $_{HEP}$, heavy impact, heavy energy pass. One is heavy energy pass that is by deep dynamic, that tamping. Another is ironing pass that is IP. So, you can see AE $_{HEP}$ multiplied by AE divided by $H_d$ $W_t$.

$$N_d = \frac{AE_{HEP} \times A_c}{W_t H_d} = \frac{3175 \times 3 \times 3}{20 \times 27 \times 10} = 5.3m$$

This equation already I have discussed in the to calculate number of drops, this I have already discussed in the lecture 13 or somewhere. So, if you do this and what is AE? That is also equivalent area, influencing area that also you have mentioned, you have also shown. And so, when is a square pattern, the influence area is same as the spacing square. So, the heavy impact, heavy energy pass, energy requirement each pass is 3175.

And AE is the area of the influence is 3 into 3, because you are, you are assuming 3meter spacing. And, and this but for unit conversion the 10 is coming, 9.8 I could have taken but 10 I have taken. A $W_t$ $H_d$ actually 20 and 27. By doing this calculation, I am getting a number of drops 5.3, 5.3 means I cannot make exactly 5.3 drops. I will go for 6 drops in each pass. This is the way, we can, and we have to design the drops and other things. Let me go to next slide.

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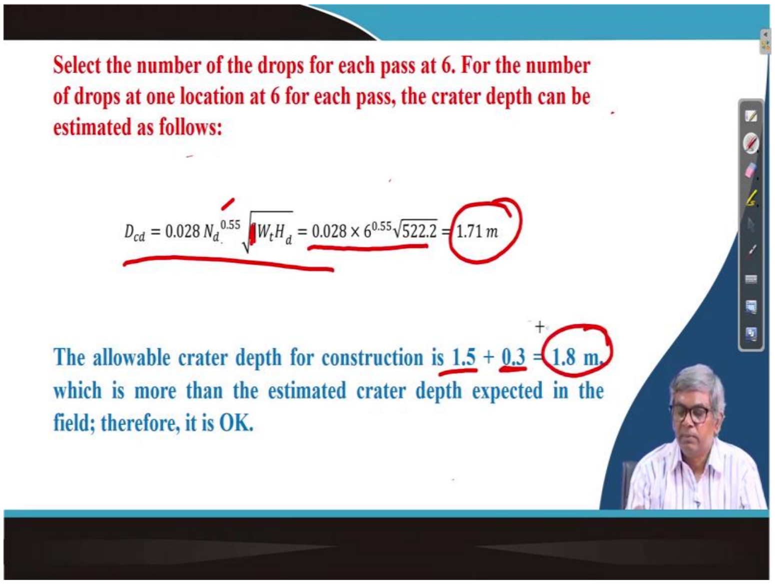


And select, select the number of drops for each pass at, so 6 as I have mentioned. And for the number of drops at one location, at 6 for each pass the crater depth can be again calculated, there is equation for crater depth, calculate two equation I have given. One equation is little complicated, one is another is comparatively simple.

I have used simply equation only, the Dcd, the depth of crater, the crater depth equal to 0.028 Nd to the power 0.55 under root $W_t$ $H_d$. So, there is left side there is something, it is nothing by mistake it has come. If I do calculation, this it comes 1.71meter, crater depth. And the permissible crater depth is 1.5 his height plus 0.3 additional. So, 1.8 but it is 1.7 that means it is acceptable and okay.

$$D_{cd} = 0.028 N_d^{0.55} \sqrt{W_t H_d} = 0.028 \times 6^{0.55} \sqrt{522.2} = 1.71 m$$

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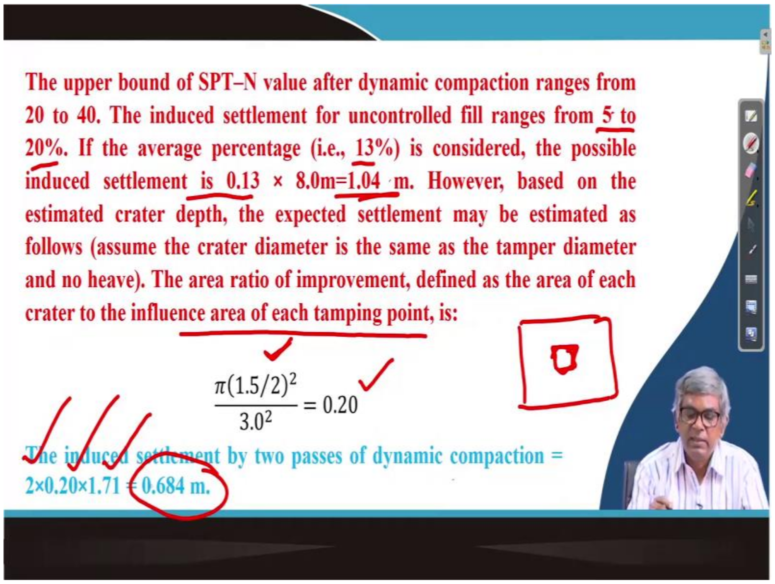


And you know that SPT N value requirement is 20. And the upper bound of SPT N value after dynamic compaction ranges from 20 to 40, there is a table I have shown maybe there in this, I will show you in the next slide. So, 20 to 40, our requirement is 20 that meant this is okay. So, the induces settlement for uncontrolled fill ranges from 5 to 20 percent, that is also given in the table form.

$$\frac{\pi\left(\frac{1.5}{2}\right)^2}{3.0^2} = 0.20$$

I will also show here, how we are doing. 5 to 20 percent is the settlement. If the average percentage is taken 13, so between 5 and 20. I will take 13 percent is consider, the possible induced settlement is 0.13 multiplied by 8.0 is equal to 1.04 meter. However, based on the estimated crater depth, the expected settlement will be estimated as, that also can be done.

How the area ratio of the improvement defined as the area of each crater to the influence area of that, this is the area of influence. So, pi this is the area influence and this is the contact area, this ratio is that is called the area ratio. And this is coming 0.2. So, that means what actually? This is the total area of influence and drop is this area.

This area ratio is 0.2, and the induced settlement by two passes of dynamic compaction can be, so 2 multiplied by the area ratio is 0.2 multiplied by crater depth 1.7. If I do this, then you are getting the settlement equal to 0.684. And your settlement is up to 1.04 is permitted, but you are getting this much settlement. So, that means it is acceptable.

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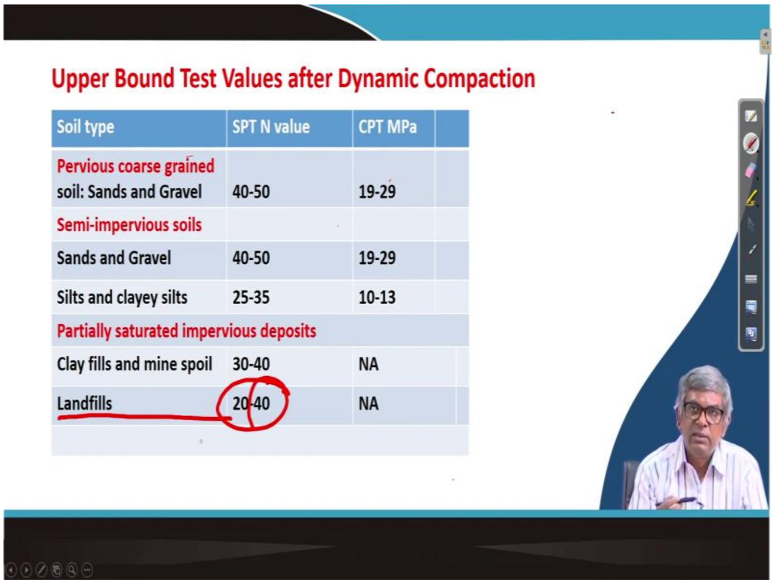


And you can see now, this these are the, as I have mentioned these are showing you can see that landfill, we have after deep dynamic compaction range of SPT value can be achieved 20 to 40. And our requirement also only for 20, if it is between, above 20 then we could have taken decision, but here since it is only 20. So, this is a lower limit. So, very much it is, can be achievable. That is okay then, acceptable.

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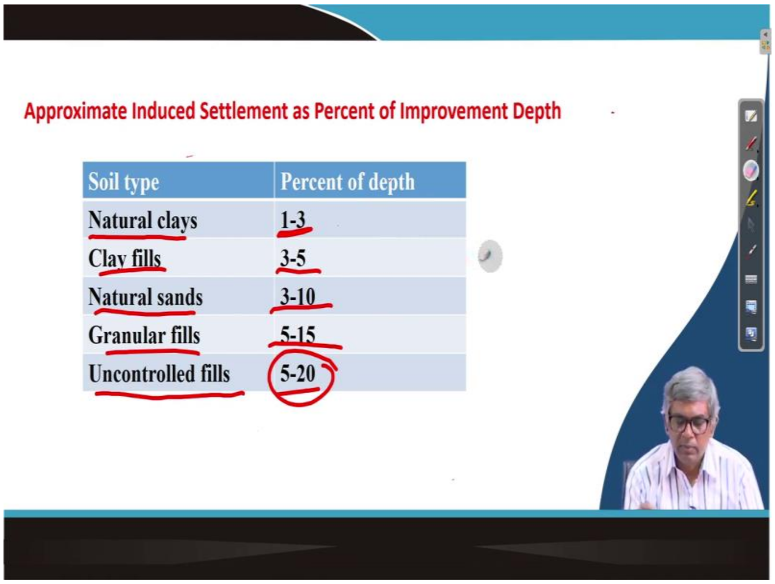

And also, as I have mentioned that, settlement that is also you can see this is the table given. Natural clays settlement can be 1 to 3 percent. And clay fills 3 to 5 percent, this is also I have shown during my lecture. Natural sand 3 to 10 percent, granular fill 5 to 15 percent, uncontrolled fills actually 5 to 20 percent. Since it is a land field, we are considering these as a, our required parameter.

So, 5 to 20 percent average is 13 and based on 13 percent multiplied by 8 deep dynamic depth, how much settlement is permitted that we have calculated and, and shown. This table also I have shown before and once again we have shown here.

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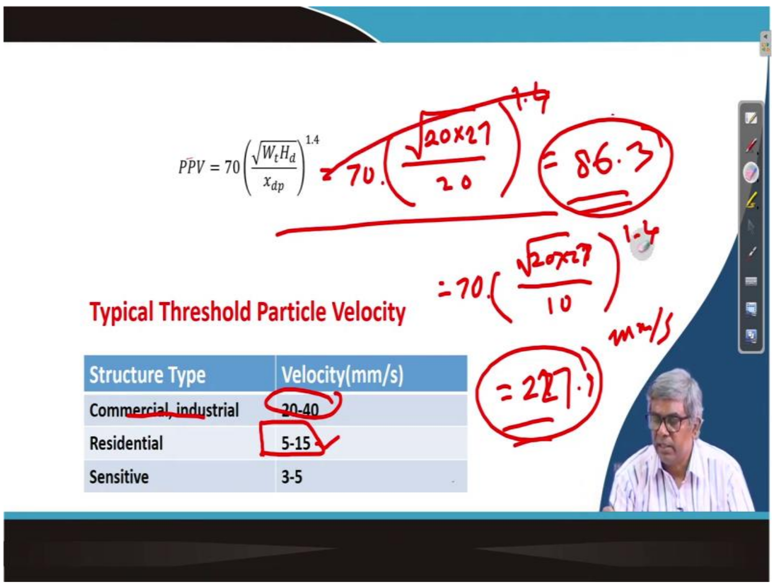


Our next part is the, the calculation of, the whether it is suitable with respect to that vibration or that that aspect. And you know that this is the equation only we have. And this equation can be used and calculate the value, and you can say whether it is acceptable or not. Peak particle velocity, one side when residential building is there, the residential area is there, distance is 20.

So, in this equation I can write 70 multiplied by under root Wt is actually 20 multiply $W_t$ $H_d$ is 27. And x dp actually is 20. So, these to the power1.4. So, let me calculate and find out the value, this is 20 multiplied by 27. This is under root, this gives you 23 divided by 20, that gives you this. And to the power 1.4, it gives you 1.23 multiplied by 70.

$$PPV = 70\left(\frac{\sqrt{W_t H_d}}{x_{dp}}\right)^{1.4} = 70\left(\frac{\sqrt{20\times 27}}{20}\right)^{1.4} = 86.3$$

$$PPV = 70\left(\frac{\sqrt{20\times 27}}{10}\right)^{1.4} = 227 mm/s$$

It is coming 86. If I do this calculation, if I do this calculation, this value is coming at 86.3. Let me check once again, 20 multiplied by 27. This is coming 540 under root, this is 23 divided by 20 and this is to the power 1.4. And then you are getting 1.23 multiplied by 70. This gives you 86, and you can see that when it is a residential building and 20meter distance. And you can see the peak particle velocity acceptable is 5 to 15 only.

But it is coming 86 that means, this project is not acceptable, or you have to redesign or what you are, have to do smaller weight. And if necessary, number of, a greater number of passes to be required that can be used, but exactly whatever design tamper weight, height we have used and based on that with respect to peak particle velocity requirement this project is failed, this is not acceptable. Similarly, if I say that other side is commercial building is there, where...

This is actually a residential building is 20 meter and commercial building has 10meter distance. So, let me see 10, 10 with 10meter with equal to 70 multiplied by under root 20 multiplied by 27 divided by 10meter to the power 1.4. This gives you 20, 20 multiplied by 27 that under root it become, divided by 10 to the power 1.4 multiplied by 70.

This gives you the velocity 227. And you can see commercial industrial with 20 to 40 whereas, it is coming to 227.9 millimeter per second. That means both sides, both side of commercial and residential from the both side objection is expected. And this project is, whatever design is done that design is not acceptable. Either you have to change the design, modifying the tamper weight and all, or we have to choose alternative method of compaction, may not be this method.

By this I tried to explain whatever in four lectures or whatever I have shown or discussed. And finally, in result is the design and how to do the design step by step? How to decide depth of improvement? How to decide, how to classify the soil? Because we have three class, a category you have to bring in either of these three categories.

And then, after that each, what is the energy required? Then because of that, how many passes you required? Then how much total energy required? How much energy required from that the tamping? How much energy required from ironing pass? Then difference of that will be energetic or total energy minus ironing pass will be required from, required from the energy from the tamping.

Once you know the energy from tamping, then from based on some equation you can find out number of drops. So, this is the complete design of deep dynamic compaction. So, with this I am closing the module there that is deep dynamic compaction. And in the next module I will start with rapid impact compaction. This is also similar type of that impact only, but here maximum depth of improvement was up to 10meter of course, not for all soil 10 meter.

For sandy soil it is 10meter. But, for silt and clay it will be comparatively less but, but advantage of these actually quickly you can cover a large area. But, sometime this type of compaction cannot be done close to the certain areas or area. That is the limitation, but rapid impact compaction again it can be done, again there are also vibration will be there, there is a limitation all those things.

But sometimes the places where is not accessible, those areas sometimes can be compacted very easily by rapid impact compaction. So, those things with, what is the concept behind, what is the advantage, disadvantage area of application all those things similar to deep dynamic compaction, I will discuss in the next module. With this I will close here. Thank you.